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LLL 18-INCH WILSON CLOUD CHAMBERS

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Abstract

A Wilson cloud chamber 18 in. in diameter and 8 in. deep is described. A number of these chambers have been used in the LLL in the "quark hunt." They have versatile electronic controls and operate at about atmospheric pressure and ambient temperatures. Operating parameters and some engineering details are given. Some of the difficulties in the operation of the chamber are discussed.

Introduction

Several years ago, a number of Wilson expansion-type cloud chambers[1] were built at LLL and were used for electron range-energy measurements.[2] Eleven of these chambers have been used in the "quark hunt."[3] Some interest has been shown outside the Laboratory in borrowing these chambers when they are no longer in use. Convenient operating conditions and large built-in safety factors make the chambers ideal for use at large and small teaching and research institutions.

Apparatus

THE CHAMBER

The construction of the chamber and housing is shown in Fig. 1. The top glass (A) is 1-in.-thick crown glass with a quarter-wave length magnesium fluoride coating to decrease reflections. The glass is held in place with a clamping ring (C) and is sealed to the chamber cylinder (B) with neoprene bell-jar gaskets (L). Some chambers have top glass without the beveled edges, in which case the clamping ring is turned over.

Fiducial marks on the top glass are made with a diamond pen (except on Herculite glass); a template is put over the glass to guide the pen. Good marks can also be made with the kind of laboratory ink used for marking glass or porcelain. The marks define 2-in. squares with an accuracy of ±20 mils.

The glass cylinder shown was cut from an 18-in. bell jar. Lucite cylinders have also been used and are very satisfactory because of the ease of machining and assembly.* Another product, Homalite, has been used to make cylinders; Homalite has the additional property of

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*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U. S. Atomic Energy Commission to the exclusion of others that may be suitable.

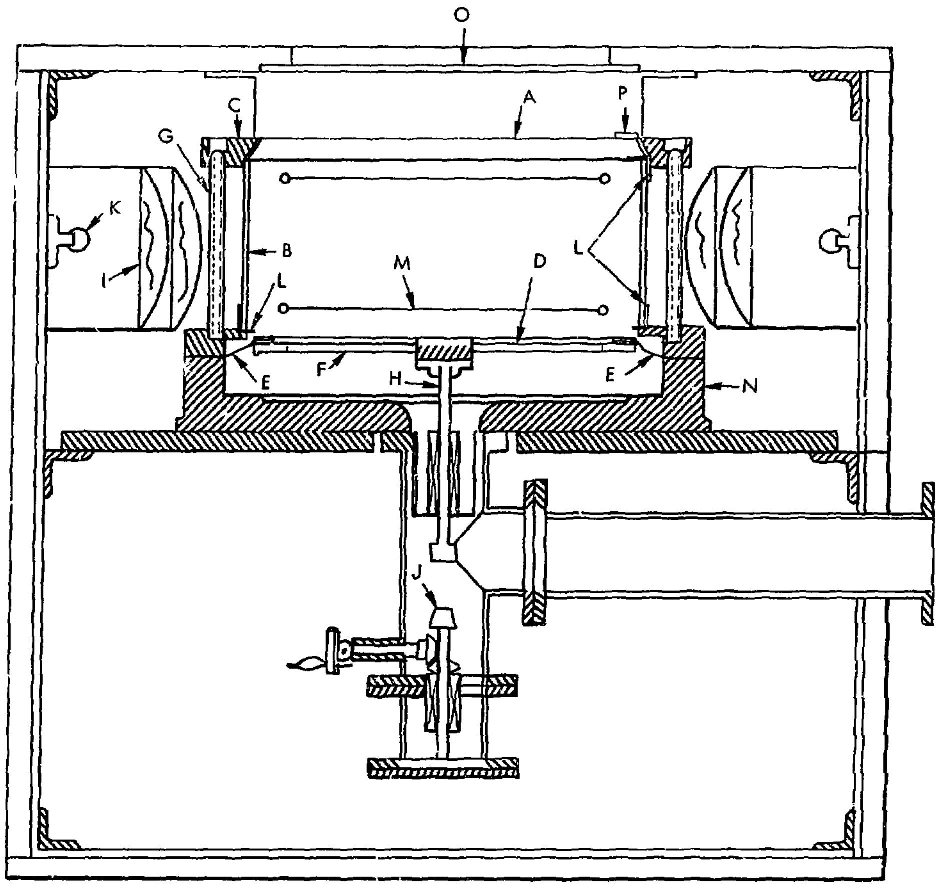

Fig. 1. Construction of the cloud chamber and the black box that houses the chamber: (A) 1-in. top glass, (B) glass, Lucite, or Homalite cylinder, (C) top-glass clamping ring, (D) black velvet, (E) neoprene rubber gasket, (F) platen, (G) 1/2-13 threaded stock, (H) 1/2-in. stainless steel rod, (I) Lucite lens, (J) epoxy foot, (K) strobe lights, (L) neoprene bell-jar gaskets, (M) clearing-field grid wires, (N) black anodized aluminum chamber body, (O) 1/4-in. glass viewing port, (P) heating tape.

not crazing in the presence of alcohol. We glue the clearing-field grid wires (M) to the chamber cylinder wall. A very satisfactory clearing-field assembly can be made in this way, if the proper epoxies and curing times are used. The leads to the clearing field can be attached through feedthroughs in the chamber body (N), or through holes in the cylinder wall.

The bottom platen (F) is covered with black velvet (D) to provide a nonreflecting surface for photography. The velvet is glued on with Vulcalock cement and left to dry from 12 to 24 hr. The velvet should then be washed with alcohol to remove any oils left from manufacture. The rubber diaphragm (E), which is attached to the platen and chamber body, is 1/16-in. neoprene. On the back side of the platen is a 1/2-in. stainless steel rod (H) that runs through bearings and comes to rest on an adjustable screw; this screw adjusts the expansion ratio of the chamber. The steel rod has a foot (J) made of soft Adiprene epoxy, which cuts down on the bouncing of the platen and lessens the chance of producing tracks distorted by gas turbulences.

EXPANSION SYSTEM

The fast expansion exhaust is controlled with a 3-in. Flexflo (boot) valve as shown in Fig. 2. The valve is held closed by the recompression pressure passing through a normally open 3/4-in. three-way Ross valve (J in Fig. 3). A positive pressure is required to open the Flexflo valve, so a small recompression pressure is enough to keep the valve closed. To expand the chamber, the Ross valve exhausts the air around the rubber boot (Fig. 2) into a vacuum system; the air pressure within the boot then opens the valve. It takes 30 msec to open the valve and empty the excess air behind the platen, and another 20 msec for the chamber to expand. This time is slow compared to some operating chambers, but we are interested in sources pulsed at controlled times. In the "quark hunt" we used diffuse tracks, and did not need a fast expansion. A faster expansion system could be made easily, if needed. As an alternative to the Flexflo and Ross valves, a 4-in. solenoid valve is available; it is slower, noisier, but it does not require a vacuum system.

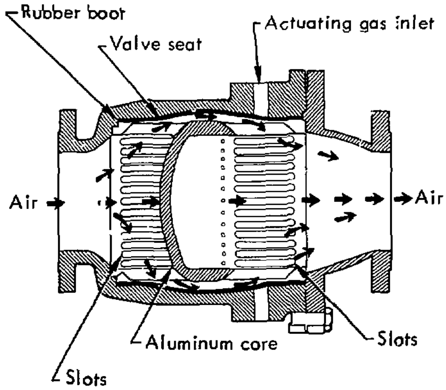

Fig. 2. The fast expansion valve is a 4-in. Flexflo Model 80. (After Fig. 883NK in Grove Valve and Regulator Co. catalog.)

The slow expansion valve (another 3/4-in. three-way Ross valve) also controls the recompression pressure (Fig. 3). Normally, the flow from a Moore regulator through the Ross valve recompresses the chamber. To expand the chamber for a slow expansion, the recompression pressure is shut off, and the pressure behind the platen is dumped to atmosphere. The slow expansion is fast enough to cause condensation on charged or uncharged nuclei that have not been removed by the clearing field, but slow enough to avoid making any more background droplets. The slow expansion should be of long enough duration to allow the droplets to grow big and fall out by gravity. The Moore regulator is a very accurate high-flow pressure regulator that allows the chamber to recompress in about 500 msec. A pressure relief valve that has been set at 12 psig is provided in case the Moore regulator

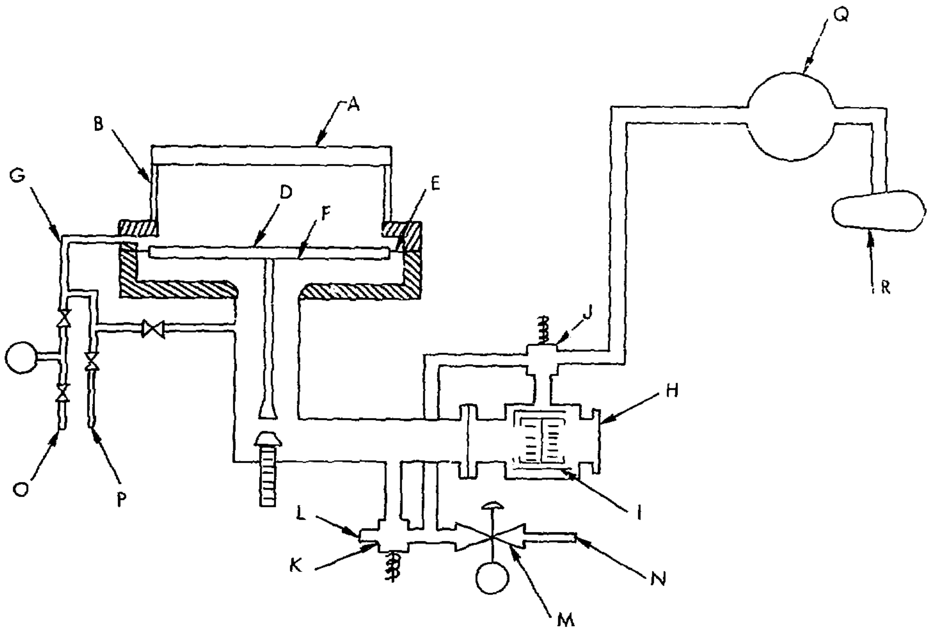

Fig. 3. Plumbing diagram for the chambers. Items A through F are typical parts of the chamber as listed in Fig. 1. (G) fill line, (H) boot valve, (I) rubber boot, (J) 3/4-in. Model 2674A5001 Ross valve that controls the fast expansion, (K) Ross valve that controls the slow expansion, (L) exhaust for slow expansion, (M) Moore regulator, series 42H100, with 0-15 psi gauge, (N) 60-psi air supply, (O) gas fill, (P) vacuum pump for purging chamber, (Q) vacuum reservoir, (R) vacuum pump.

malfunctions. There is also a relief valve on the chamber body (N) that has been set at 8 psig in case the rubber diaphragm (E) ruptures (Fig. 1).

The chambers can be operated at pressures less than 1 atm. To do so, a Matheson vacuum regulator is used instead of a Moore regulator to control the recompression pressure. The LLL chambers have been operated as low as 1/4 atm. To expand the chamber, the air for the recompression is dumped into a large reservoir that has been pumped down to the base pressure of a vacuum pump. The platen is forced down by the pressure of the gas in the chamber, expanding the chamber. The recompression pressure is set 100 Torr above the chamber pressure.

ILLUMINATION

The lights, K in Fig. 1, are 24-in. FT-422 General Electric strobe lights, or the equivalent. Each light has a 2-kV, 256-μF capacitor bank and is triggered with a 15-kV trigger transformer. The lights have aluminum foil wrapped halfway around them; they are laced with 15-mil copper wire in 1-in. coils along the light tube. The aluminum foil not only acts as part of the trigger circuit, but reflects the light from the back side of the bulb toward the chamber.

A new paint, Eastman White Reflectance Paint, which increases the light in the chamber by 20%, is now being placed on the lights instead of the aluminum foil. The trigger wire is wrapped along the light tube; a 1/4-in. slit is masked off, the bulb is painted, and the mask is then removed.

The condensing lenses (I) are plano-cylindrical-convex and are made from Lucite. The convex surface has a radius of curvature of 6 in. The lenses have been masked to a clear aperture of 4 in., which is then the limit of the illuminated depth of the chamber.

PHOTOGRAPHY

We use four Nikon 35-mm single-lens reflex cameras for each chamber,[2,3,4] with 55-mm, 105-mm, and 135-mm lenses. The 105-mm and the 135-mm lenses have extension tubes for close-up photography. After trying many different types of cameras, both manufactured and homemade, we found it more economical to purchase the large number of cameras we needed rather than to build them. We chose the Nikon camera because of its motorized back and excellent 55-mm lenses. We use both small 36-exposure and large 250-exposure motorized backs for remote controlled operations.

The film used is Linagraph Shellburst, developed in Acufine for 14 min at 78°F. We are now using reversal film, Eastman 2498, in addition to the Linagraph Shellburst.

TEMPERATURE CONTROL

The black box that houses the cloud chamber is divided into two parts. The upper part houses the chamber and the lights; the lower part, the expansion system and the electrical panel. The chambers are normally operated at a temperature a few degrees below room temperature, making the top glass less likely to fog up. Temperature-controlled water is circulated through a heat exchanger (an automobile heater) outside the black box. Recirculating air is blown over the cooling coils and then into the lower half of the box. Here, the cooled air comes in contact with the expansion system and the bottom of the chamber. It is then drawn to the upper half of the box, where it circulates around the cloud chamber evenly so as to avoid distorted tracks due to heat gradients. The temperature-controlled water in the heat exchanger is kept constant within 1/4°C to provide a constant even flow of regulated air. We try to keep the chamber body a quarter of a degree cooler than the top glass to prevent condensation from forming on the top glass. To further prevent condensation, we use a heating tape (controlled with a variac) around the perimeter of the top glass.

ELECTRONICS

The controls for the operation of the cloud chambers have been kept flexible. All of the standard functions can be set up on a single control panel. We have an electronic chassis for each chamber so that each chamber can be varied to fit its own set of problems. Each chassis is composed of the following components: (1) a light-tickler power supply to provide a 300-V pulse to a 15-kV trigger transformer to trigger the lights; (2) an oscilloscope for observing the pressure transducer signal, the timing of the lights, and the source shutter (Fig. 4); (3) a Nixie readout for timing of the chamber; (4) variable adjustments for the timing of slow expansions, fast expansion delay, fast expansion duration, source shutter timing, and light delay; (5) a relay panel with on-and-off switches that activate the cameras, the fast expansion, the clearing field, and the source shutter; and two 24-V power supplies that control the various chamber operations; (6) two 2-kV power supplies for the strobe lights.

One cannot hope to provide in a standard panel all of the functions an experimenter might need. However, in our chambers all of the functions terminate on easily accessible terminal strips at the back of the chassis. This facilitates changing and adding functions. In spite of this convenience, additional small "black boxes" seem to appear with each experiment.

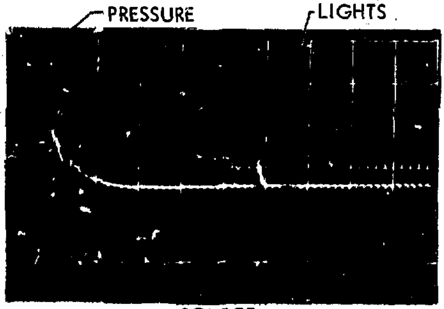

Fig. 4. A typical timing picture. Sweep time is 50 msec/cm. The time for the fast expansion is slower than in some chambers because of the desired mode of chamber operation.

CLEARING-FIELD GRIDS

A clearing field has to be maintained inside the chamber to remove the ions that are formed from passing cosmic ray secondaries. The clearing-field grid system was made to adhere to the glass or Homalite in an atmosphere of water and alcohol. It might be of some interest to know how the grids were attached to the cylinder walls and what epoxies were used. We found that we had to protect the epoxy with a nonwetting agent because most epoxies are attacked by alcohol. Also care must be taken not to contaminate the chamber.

The following list of materials and procedures is a guide for using epoxies inside the sensitive area.

1. The first step is to clean the cylinder with Ivory bar soap, rinse with distilled water, and then rinse with ethyl alcohol.

2 The terminal lugs, or whatever one wishes to fasten on the cylinder walls, are then attached with Torriseal epoxy. The epoxy should be cured for 24 hr.

3. Paint the Torriseal epoxy and any exposed metal with General Electric SS-4004 silicone primer. Let dry for one-half hour.

4. Then coat with R.T.V.-60 silicone rubber that has been mixed: 50 g R.T.V.-60 to 13 drops curing catalyst, dibutyl tin dilaurate. Let cure for 24 hr at 100°F.

5. Paint the silicone rubber and all exposed parts with Plastic Carbo-

lene (black) series K-23. Mix paint: 25 g to 17 drops of A-1100 adhesive promoter. Let dry at 100°F for 24 hr.

6. The cylinder and all parts should then be washed with ethyl alcohol to remove any fingerprints or oils that might have contaminated the cylinder during assembly.

Discussion

CLOUD CHAMBER OPERATION

A typical operating sequence for one of these cloud chambers is as follows.

1. A series of slow expansions is made to clear away old nuclei and uncharged centers of condensation left over from the last fast expansion.

2. A period of time is allowed for the chamber to sit in a compressed state and come to equilibrium. This period of time should be kept constant for reproducible operation.

3. A signal is given to expand, triggering the following sequence of events:

   a. The clearing field is turned off.
   b. The camera shutter opens.
   c. A fast expansion occurs.
   d. The chamber is exposed to radiation at the proper time.
   e. The strobe lights flash.
   f. The camera shutters close.
   g. The chamber is recompressed.
   h. The clearing field is turned on again.

4. Another series of slow expansions is made and then the chamber is ready for another fast expansion.

SOME CHAMBER PROBLEMS AND HOW TO FIX THEM

Contamination and an improperly operating clearing field cause 90% of the problems we have had with the chambers. Some of these problems, their causes, and their cures are listed in Table 1.

To remove contamination such as oil or greasy fingerprints we use an old and proven method of cleaning. The glass or Lucite cylinder, top glass, rubber diaphragm, and anything else that goes into the sensitive area of the chamber, should be cleansed with old-fashioned Ivory bar soap. The Ivory soap should be removed with distilled water and then rinsed off with ethyl alcohol. We can hold our backgrounds, due to contamination, to less than 0.05 drop/cm^3.

We primarily use Tygon Plastic paint and Vulcalock cement inside our chambers. This paint and cement do not contaminate cloud chambers. We have used epoxy and silicone rubber with some success, but care must be taken in the selection of the epoxies because some are attacked by alcohols. We make a rule that if the substance is dissolved by alcohol, or if it has an odor, it should not be used inside a cloud chamber.

An improperly designed or improperly operating clearing field will result in a contaminated chamber. If there is leakage current between the grids, the clearing field will be destroyed, electrolysis will occur, and a clean chamber that is free of background will never be obtained. Tracks may still be seen, but never without background.

Table 1. Some chamber problems, causes, and cures.

Problem	Cause	Cure
Background	1. Contamination.	1. Clean the chamber and all fill lines. Flush the fill lines with alcohol. *All metal surfaces inside sensitive area should be painted with black Tygon paint.*
	2. Poor clearing field.	2. Check to be sure clearing fields and terminals are absolutely insulated from one another. Voltage between grids should be about 30 V/cm.
	3. Overexpansion.	3. Raise platen-stop (J in Fig. 1) and bring down slowly. Droplets will form first on ions before forming on background-causing nuclei.
	4. Not enough time between fast expansions (too rapid expansion of rubber diaphragm).	4. Lengthen time between fast expansions.
	5. Not enough slow expansions or enough time for droplets to fall.	5. Allow more slow expansions and lengthen time for droplets to fall out. 5-10 sec for He and H_2, 10-15 sec for N_2, 15-20 sec for Ar.
	6. Radioactive sources.	6. Check for radioactive sources and remove from area.
Chamber not sensitive	1. Not enough recompression pressure.	1. The recompression pressure should be 2 psi gauge pressure over chamber pressure to firmly seat the platen against the stops.
	2. Not enough pressure in chamber.	2. Chamber pressure should be enough to push platen down against expansion-adjusting stop. There should be at least 3 psi gauge pressure inside chamber.
	3. Chamber dry.	3. Droplets will become small and it will become necessary to keep increasing the expansion ratio to keep chamber sensitive. Add liquid (~50 cc).
	4. No fast expansion.	4. Check Ross valve on boot valve. Make sure boot is opening. Rubber boot could be ruptured.
Poor droplet size and faint tracks	1. Not enough liquid, chamber going dry.	1. Add liquid if going dry. At least 50 cc but not over 100 cc. Too much liquid will splash.
	2. Fog on cylinder walls.	2. Wait a longer time between expansions. Adjust air flow around chamber cylinder. Fog causes light to diffuse, reducing the apparent droplet size.
	3. Lights.	3. Lights may get cloudy; if so, replace them. Slot on light tube may have rotated out of position.
	4. Light timing.	4. Increase light time delay. Time should be about 150 msec after bottom of pressure valley.
	5. Top glass foggy.	5. Check heater tape. Recompressing chamber could raise temperature of gas above top glass temperature. Wait a longer time between fast expansions.
No lights or missing lights	1. Light bad.	1. Replace light if it looks foggy. Check to see if light triggers with trigger supply. It should trigger with no high voltage on light.
	2. Trigger voltage too low.	2. Trigger voltage should be set just high enough to trigger lights. This increases life of lights. If lights start to fail, increase trigger voltage. Check leads from transformer mounted near light for grounding.
	3. Capacitor bank blown.	3. Check capacitor banks for blown fuses. Replace blown capacitor.
Top glass foggy	1. Air conditioner off.	1. Make sure air conditioning is still working. Blower may have burned up. Raise voltage on top-glass heater tape. Keep temperature difference between top glass and chamber body 1/4°C.
	2. Heater on top glass fails.	2. Usually variac shorts out; check and replace.
	3. Not waiting long enough time between fast expansions.	3. The fast expansion and slow expansions warm the gas inside chamber and liquid will condense on the top glass for a few minutes. Allow more time for chamber to come to temperature equilibrium.
Chamber cylinder foggy	1. Temperature.	1. Redistribute air flow around chamber body. Chamber should be at least 1/4°C colder at bottom but not more than 1/2°C.
Distorted tracks	1. Temperature gradients.	1. Redistribute air flow around chamber body.
	2. Turbulence in chamber.	2. Platen should be centered on rubber diaphragm; check platen to see if it is parallel with top glass when chamber is expanded.

Contamination droplets can also come from dust particles or sharp points on clearing-field grids. These particles can become ion emitters if left there. The higher the voltage on the clearing field, the more ions are created. A chamber, when assembled, may never become clean, no matter how many slow expansions are used, because of dust particles or sharp points. These become quite apparent with the first fast expansions.

Another problem is fog on the cylinder walls. This is caused by improper chamber cooling or insufficient time between fast expansions. The fog scatters the light, making the velvet glow and decreasing the apparent droplet size because of the loss of illumination of the droplets.

Backgrounds have also been caused by the rapidly expanding rubber diaphragm. This background cannot be removed by the the clearing field. We use at least two slow expansions between fast expansions. Since rapid expansion also causes heat gradients, we allow time for the gas in the chamber to come to an equilibrium. One should wait 1 to 20 min between fast expansions, depending on how fast the expansion is: 1 to 3 min for a fast expansion 300 msec long, and 15 to 20 min for a fast expansion of 20 msec. Here, fast expansion refers to the length of time during which the pressure is changing.

The design of the clearing field can also cause what appears to be background. Old tracks, if swept across the chamber and across the field of view become diffused because of the random movement of the ions and appear as background. The clearing field should be in line with the expansion axis of the cloud chamber; thus the old tracks have a shorter distance to be removed from the visible part of the chamber.

Conclusion

The expansion cloud chamber is basically a simple machine. Our chambers have been made easy to operate and maintain. Because of the mode of our operations, the chambers have had to be trouble-free and dependable. In the "quark hunt," for example, they can operate two to four months without adding liquid or gas, or requiring any maintenance. (The liquid that is lost diffuses gradually through the rubber diaphragm.) The chambers also work well in short-term applications. We have had them apart as many as two or three times a day, making changes inside the sensitive area, and have sometimes been able to take data within an hour after reassembling. The chambers are very flexible and may be used in any way an experimenter wishes.

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